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MEASUREMENT AND IMPLICATIONS OF PRODUCTION LEAD TIME VARIABILIT--ETC(U)
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IRO REPORT No.229

MEASUREMENT AND IMPLICATIONS OF PRODUCTION LEAD TIME VARIABILITY

US ARMY
DARCOM

U.S. ARMY
INVENTORY
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OFFICE

September 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the final report for the US Army Inventory Research Office study, "Measurement and Implications of Production Lead Time Variability," (Proj 229). It describes empirical work on methods of forecasting Production Lead Times for secondary items. The forecast and a measure of its variability are to be used in the Variable Safety Level (VSL/EOQ) module of the Commodity Command Standard System. A six-year data base of the procurement history for aviation components was compiled and utilized in simulations of the candidate forecast

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methods. A method was selected on the basis of smallest aggregate forecast error. A test of this method suggests a significant improvement over the presently-used forecast method.

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SUMMARY

1. Background

In the early 1970's various economic problems resulted in increased difficulty in acquiring defense materiel. For secondary items we experienced higher prices and more difficulty in placing contracts. It was also felt that production lead times (PLT) were increasing. The Air Force responded by increasing the emphasis given to recent buys in forecasting PLT for future buys. The Army, in an emergency measure, shifted from using a two-year average of PLT for the item to be bought, to the PLT of the last representative buy. The Materiel Development and Readiness Command (DARCOM) sponsored this research to study the consequences of this change and to improve PLT forecasting.

2. Purpose and Objectives

The purpose of the study was to develop improved forecasting methodology for PLT and compensate for the random error with an increase in safety level investment. The individual objectives are summarized under Scope and Methods below.

3. Scope and Methods

In scope this was an empirical study of secondary items used in repair of weapon systems. The forecast method and variance estimate are to be incorporated into the Commodity Command Standard System (CCSS) for wholesale supply management. Specifically they are to be made part of the replenishment computations in the Variable Safety Level/Economic Order Quantity module (VSL/EOQ).

The methodology consisted of assembling a data base of aviation-component procurement, developing forecast methods, testing them by deterministic (not Monte Carlo) simulation using the data base, selecting the best-performing method, and comparing it with the presently implemented method.

4. Conclusions and Findings

The emergency measure - changing to a forecast equal to the latest

representative PLT - was found to be ineffective in the long run.

Several better forecast methods were found. The best-performing method uses the present age of buys that have not been shipped yet in an average along with the PLTs of buys shipped in the last two years. It also makes use of an average of the PLTs of items bought on the same contract type to fill in when the item's own data is limited (few buys in the two-year base period.)

Implementing this method should considerably improve supply performance and reduce safety level (estimated TSARCOM ASF reduction of $15 million).

INTRODUCTION

The purpose of this study was to develop an improved method of forecasting production lead time as used in requirements computations for procurement of weapon system support items on a recurring basis, and to determine the statistical variability of this forecast also to be used in the computation of requirements.

The study methodology was thus: First a data base was built. This consisted of a record of every procurement over a period of six years for all secondary items bought by the US Army Aviation Systems Readiness Command (AVSCOM), now merged with the US Army Troop Support Command (TROSCOM) and called the US Army Troop Support and Aviation Readiness Command (TSARCOM). In this report, the source of the data will be referred to as AVSCOM. Some data for part of the study came from TROSCOM. The second phase of the study developed and evaluated several forecast methods. These methods make use of the information in the data base in the same way they would when installed in the Commodity Command Standard System (CCSS). The evaluation consisted of comparing the forecasts at an assumed present date (which were made using data which was known prior to the present date) with the actual PLT (which would not become available until after the present date). This present date was set to the latest time at which a forecast could be made in time to influence the buy whose actual PLT was used for comparison.

There was also an attempt to identify information beyond that inherent in the procurement history of the items stocked, information such as the economic time series found in Business Conditions Digest. However, as reported below, the most promising such data seemed to have no relation to the procurement experience, and would thus be of no use in forecasting.

The remainder of this report explains how the PLT forecast is presently made and how it fits into the requirements computation process, work done by other organizations in this area, the characteristics of the data base, the forecast methods and how they were evaluated, the results of the evaluation including the final ranking of the methods and other issues that were studied, and some suggestions for additional work.

I wish to acknowledge the contributions of many people in IRO, DARCOM, TSARCOM, ALMSA and CERCOM. At IRO, valuable guidance and suggestions were received from Alan Kaplan, Bernard Rosenman, Sally Frazza, Edwin Gotwals, and others. At TSARCOM, much help was received from Marsala Young, Eleanor Wills, Charlie Markowitz, Chris Moulder and Dave Coppens, Planning & Policies; Don Doll and Richard Green, Production; At ALMSA, Judy Johnson, Gary Jones, Dick Touch and Charlie Freeman. The first briefing was presented to Bill Hershowitz, etc. at CERCOM; their suggestions improved the work. I also drew ideas from Larry Wheelock's "Production Lead Time Forecasting," IRO, January 1972. Sally Frazza read the first typed draft and made many suggestions that improved the exposition. Marie Francis did the typing and made sense of the mathematical notation.

CHAPTER 1

HOW PLT FITS INTO CCSS

1.1 Current Forecast Method

A PLT is recorded for each contract for which shipment of at least one-third of the quantity ordered has been completed. The sum of the PLT of the latest buy, the ALT, and 30 days (to allow for delivery) is used to update the PROLT field in the NSNMDR. This field is subject to manual change as well as, since May 1975, to an optional freeze code; i.e. it can be prevented from being reduced.

The ALT (but not the delivery time) is then subtracted from the PROLT to yield the final value for PLT which is used in requirements computation. The PROLT is recomputed as needed by adding the latest ALT to the latest PLT (which may be from different buys because the ALT becomes available before the PLT).

1.2 Requirements Computation

This PLT is used to compute the reorder warning point. The first order effect is that the average stock level increases proportionally with the PROLT.

The second order effect of the PROLT is to slightly increase safety level, and it also acts as an upper bound on the safety level.

1.3 Variance

The variance of the PLT forecast error is not presently used in requirements computation, but methodology for using it has been developed and it is now being incorporated into CCSS.

When a good PLT forecasting method has been implemented, the effect will be a reduction in this variance. Then a more accurate safety level can be computed by including this variance. This will cause a slight increase in requirements levels.

The formula which includes both variance of demand and of lead time is derived by considering the lead time demand as consisting of a random number of months of random demand.* This "lead time" includes both the ALT and PLT, but we are concerned here with the variance of the PLT.

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*Emanuel Parzen, Stochastic Processes, Holden-Day, Inc., San Francisco, 1962, p 131.

CHAPTER II

DESCRIPTIVE STATISTICS OF PLT DISTRIBUTION

2.1 ARRCOM Work

ARRCOM studied lead times using the December 78 NSNMDR. ALTs were found to be at least as much of a problem as PLTs, but only the results for PLTs are included in our scope. Most of the ARRCOM buys are for ASF items. This study shows an increase in the number of buys as well as in the average PLT, at least since July 1976. The average went from 4.2 months in FY77 to 4.9 months in FY78.*

2.2 TARCOM Work

TARCOM studied a ten-percent random sample of the 4000 highest demand items. Again ALT was found to be at least as variable and increasing as fast as PLT, but we look only at results for PLTs. The average for buys over $10,000 was 6.7 months, and for buys under $10,000 was 5.3 months. For under $10,000 PLTs varied from 0 to 13 months with outliers up to 19 months. For over $10,000 they varied from 0 to 15 months with outliers to 19 months also. The coefficient of variation was about 0.5.**

2.3 IRO Work with TSARCOM Data

TSARCOM Troop Support Data studied by IRO.

YEAR	# SHIPPED	AVG PLT MOS.
1969	1399	4.9
1970	868	4.4
1971	1099	3.4
1972	639	3.4
1973	672	3.0

We observed a decreasing trend from 1969 to 1973 for both number of buys and average PLT at TROSCOM.

For aviation items our data base covers a more recent period (following table).

---

* ARRCOM Memorandum for Record, DRSAR-PES, February 1979. A report by Norman Trier is forthcoming.

** Maryann Dominiak, "Procurement Lead Time Forecasting Analysis," TARCOM SA-79-14, May 1979.

TSARCOM AVIATION ITEMS

YEAR	# SHIPPED	AVG PLT MOS.
1972	13175	7.0
1973	10040	5.9
1974	11517	6.5
1975	12676	6.9
1976	10426	7.5
1977	10813	7.3

TABULATED BY SHIPMENT DATE

There is almost no observable trend even though it was during this period that we had severe economic problems and materials shortages. One reason we do not observe a trend is due to the way the data is displayed. The averages are computed for the year the data became available (the shipment date) rather than the contract date. Since the trends would most likely be associated with the contract date, but the randomness of PLTs causes contracts signed in the same year to be shipped in different years, presenting the data by shipment date tends to obscure trends. However, the alternate method of presentation, by contract date, tends to introduce spurious trends due to truncation of the PLT distribution.

YEAR	# SHIPPED	AVG PLT MOS.
1972	7741	6.1
1973	13316	6.7
1974	11321	7.2
1975	12852	6.5
1976	9453	7.1
1977	8411	6.9

TABULATED BY CONTRACT DATE

If we look at this table with the understanding that any lead time over one year has been left out of 1977, over two years from 1976, etc., we see that there may well be an increasing trend. From a study of the PLT distribution, it was found 89% of the PLTs were less than one year, and essentially all of the rest were less than two years. The mean lead time

over one year seemed to be about 16.5 months. Thus we can estimate that the average for 1977 should be about 8.3 months (6.9 x .85 + 16.5 x .15), which does suggest a trend.

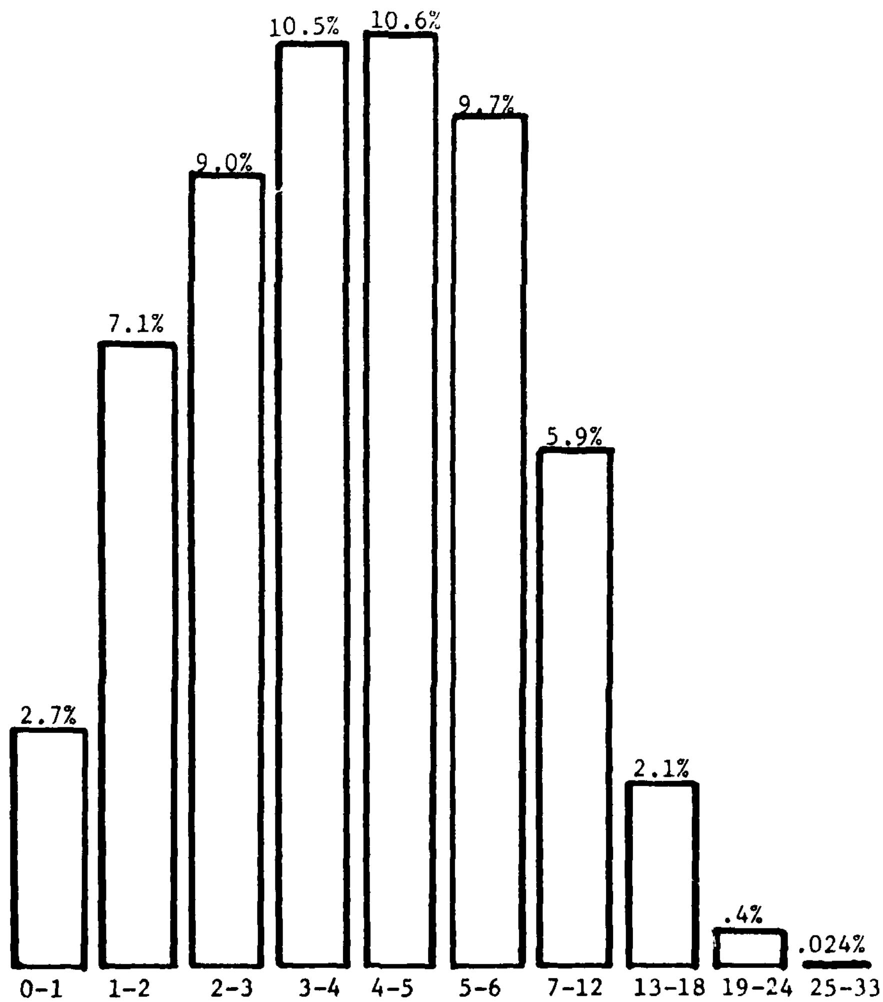
The following bar graph presents the empirically determined distribution of aviation component PLT. Approximately 21% (10.5 + 10.6) of the observations were between three and five months. To interpret the three bars at the upper end of the distribution, an average of 2.1% of the observations appeared at each of the six months from 13 to 18, a total of 12.6% of all the data. Note the characteristic departure from symmetry, i.e. the heavy tail and truncation at zero (no negative PLTs). The mean is about 7.6 months, the mode about 4.5 and the median a little over 6. The standard deviation of the PLT distribution should not be measured over the whole data base because it would be confounded with non-random changes. Instead we can get an estimate of the variability of the PLT distribution, by measuring the standard deviation over short periods of time. You can also get some idea of how much non-random trend there is by comparing the standard deviation over one year with that over a shorter time, say one quarter. The within-quarter and within-year standard deviations for the years 1976 to 1977 are .522 and .537 of the means, respectively; the small increase is due to the lack of measured trend in these years (possibly due to truncation).

The next chart is an attempt to portray the migration of PLTs for the same aviation component from one buy to the next. The first PLT for an item was classified into one of the six PLT classes. Then the next PLT for the item was classified using the same set of classes. If the second PLT fell into the same class as the first, it was counted. Whether or not it fell into the same class, a total count for the class was counted up. This was repeated for each successive pair of PLTs for the item, and done for all items. To interpret the chart: In 13.5% of the pairs the first PLT fell in the 1 to 75 day class. Of these pairs 38.2% of the second buys also fell in the 1 to 75 day class.

PLT PROBABILITY DENSITY

PERCENT OF OBSERVATIONS

PER MONTH OF PLT CLASS WIDTH



PLT CLASS (MONTHS)

MIGRATION OF PLTS

PLT CLASS (DAYS)	PERCENT	PERCENT NOT MIGRATING	DAYS IN CLASS
1-75	13.5	38.2	75
76-150	22.6	37.8	75
151-200	15.3	24.6	50
201-250	12.0	20.1	50
251-325	15.0	27.3	75
326-	21.5	51.4	?
Overall		35.0	

For this particular set of PLT classes it was found that an average of 35% of the buys were in the same class as the previous buy. If there were no correlation between successive PLTs, this fraction would have been expected to be only 16%.

CHAPTER III

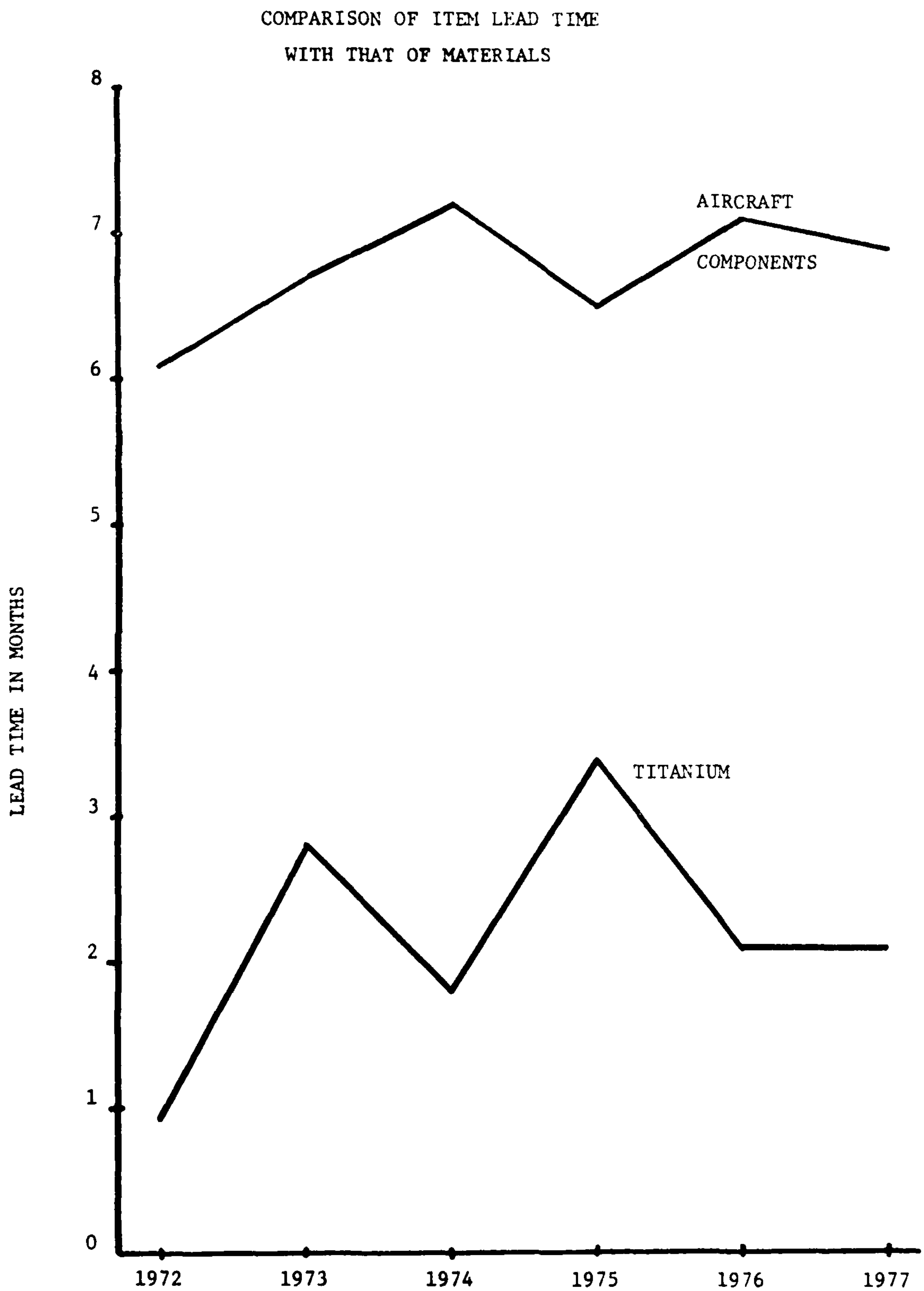
ATTEMPTS TO USE ANCILLARY DATA

3.1 Materials of Which Item is Made

Variation between PLTs can be separated into between-buy for same item and between-item components. Our work with different contract types (below) and trend (previous chapter) has suggested that each of these components is of significant impact to forecasting. This chapter discusses attempts to find parameters which would be useful in grouping items to increase statistical confidence and effectively reduce the between-item component of variance. This would be accomplished by dividing the universe of items into subsets, called a catalog, so that a homogenous group of items could be used to compute averages that would aid in forecasting PLT for individual items in the group.

Several attempts at breaking out items by various parameters have been made. The following is part of the breakout used at MICOM. It shows how PLT varies by type of material used to manufacture missile components. It is based on survey of vendors.

PLT(Wks)	PLT(Days)	DESCRIPTIONS
30-44	210-308	High Reliability PCB's Systems 04, 29, 44, 55, 92, 95
18-32	126-224	Other PC Boards
36-50	252-350	High Reliability Electronics Chassis
24-38	168-266	Other Electronic Chassis
19-30	126-210	Wiring Harness & Cables Assemblies
18-32	126-224	Wired Electrical Assemblies
12-20	84-140	Standard Electrical/Electronic Components
24-32	168-224	Special & High Reliability Electrical/Electronic Components


COMPARISON OF ITEM LEAD TIME
WITH THAT OF MATERIALS
LEAD TIME IN MONTHS
8
7
6
5
4
3
2
1
0
AIRCRAFT
COMPONENTS
TITANIUM
1972
1973
1974
1975
1976
1977

A similar breakout by type of component was obtained from Purchasing Magazine based on survey of purchasing agents. This breakout also shows change of PLT with time. IRO compared this with the changes in PLTs for aviation components and found no obvious correlation. (See graph)

3.2 Federal Item Class Identifiers

Navy's Fleet Materiel Support Office (FMSO) defined a procedure [4] for estimating replacement factors based on Item Nomenclature and Federal Stock Class (FSC). Another FMSO study [2] found that these identifiers were inadequate for estimating unit price. Defense Logistic Agency's (DLA) Electronic Materiel Center (DESC) conducted a one-time survey of current and forecasted PLT (thru the National Association of Manufacturer's Representatives) by Item Nomenclature. The resulting changes were used to update the PLTs in the requirements computation file and resulted in many buys which brought up lagging supply performance brought on by an alleged rise in PLTs. No attempt was made to determine whether stock may have been bought for the wrong items as well as some of the right items. Because DLA attempts to handle only fast moving items, perhaps an across-the-board safety level increase without the PLT change excuse would have been just as effective. Our conclusion is that there is still no evidence that Item Nomenclature or FSC can be used to classify items to improve forecasting of PLT.

3.3 Vendor Estimates

Bell Aircraft Company maintains a file of PLTs for the components they make. AVSCOM got a printed listing of this file and manually compared 75 of them with the properly adjusted values from the CCSS file and found excellent agreement. We repeated this comparison on the entire file and confirmed the agreement, but we were uncomfortable with this methodology because the values in CCSS may have been derived from Bell estimates. This is because the CCSS values are based on the promised delivery date in the most recently signed contract. We have recently tried comparing the Bell estimates with the actual lead times observed in the following two years. The results are inconclusive because of data base limitations, but they are promising. Specifically, the errors were about as large as the worst found in evaluating

statistical forecast methods (Chapter 6), but much of this error could be explained as due to bias which may have resulted from limitations in the data. Further study with better data is indicated.

3.4 Unit Price as Stratifier

Unit price should be a good way to group items for PLT forecasting. More expensive items are likely to be more complicated and thus take longer to make. Raising capital may take longer, and inspection would be more thorough.

CERCOM found a relationship between unit price and PLT for major items (see table below).

CERCOM RELATIONSHIP FOR MAJOR ITEMS

$UP	PLT MONTHS FIRST BUY	PLT MONTHS ADD-ON BUYS
500	11	8
1000	17	11
2000	19	13
3000	23	16
4000	26	18
5000	27	19
6000	29	19
7000	30	20
8000	32	21
9000	34	21
Over 9000	36	22

Source: CERCOM experience for about 1000 major item contracts ending in 1963.

Such good results for major items offers hope for secondary items. The following distribution was developed for aviation secondary items.

$UP	BUY COUNT	MONTHS AVG PLT	MONTHS STD DEV
0-350	12703	5.3	.14
351-10	10562	6.0	.15
10.01-22	10399	6.4	.06
22.01-49	11527	6.9	.11
49.01-235	17416	7.8	.05
235.01-3M	12217	10.4	.06

This distribution shows a strong relationship between PLT and unit price. A forecast method based on this relationship is evaluated below.

3.5 Dollar Value of Order

We also found a relationship between dollar value of buy and PLT:

$ ORDERED	BUY COUNT	MONTHS AVG PLT	MONTHS STD DEV
0	95	.6	.22
500	27064	5.8	.08
2000	18625	6.9	.10
10000	18945	8.3	.04
50000	7328	10.0	.07
100000	1425	11.6	.17
1000000	1231	12.6	.20
10000000	95	14.0	.94
10^{20}	16	15.5	1.75

3.6 Contract Type

The variable which seemed to be best related to PLT of aviation components is the contract type as used by TSARCOM (formerly AVSCOM). Our data base contained buys coded with five contract types as defined in ASPR:

CODE	DESCRIPTION
A	Blanket Purchase Agreements
C	Contracts, including Letter Contracts....
D	Indefinite Delivery Type Contracts
F	Delivery orders...other Government....
M	Purchase Order - manual.....

TSARCOM assigns a Basic Order Agreement (BOA) for each aircraft system. Buys are simply calls on such an agreement. Most of the buys seem to be of this type, called Blanket Purchase Agreement by ASPR.

Our data covered the years 1972 thru 1977; in that period there were considerably fewer competitive buys than BOA calls. Indefinite delivery type contracts and delivery orders on contracts of other government agencies were almost never used during that period. Purchase orders were

used very frequently for buys under $10000.

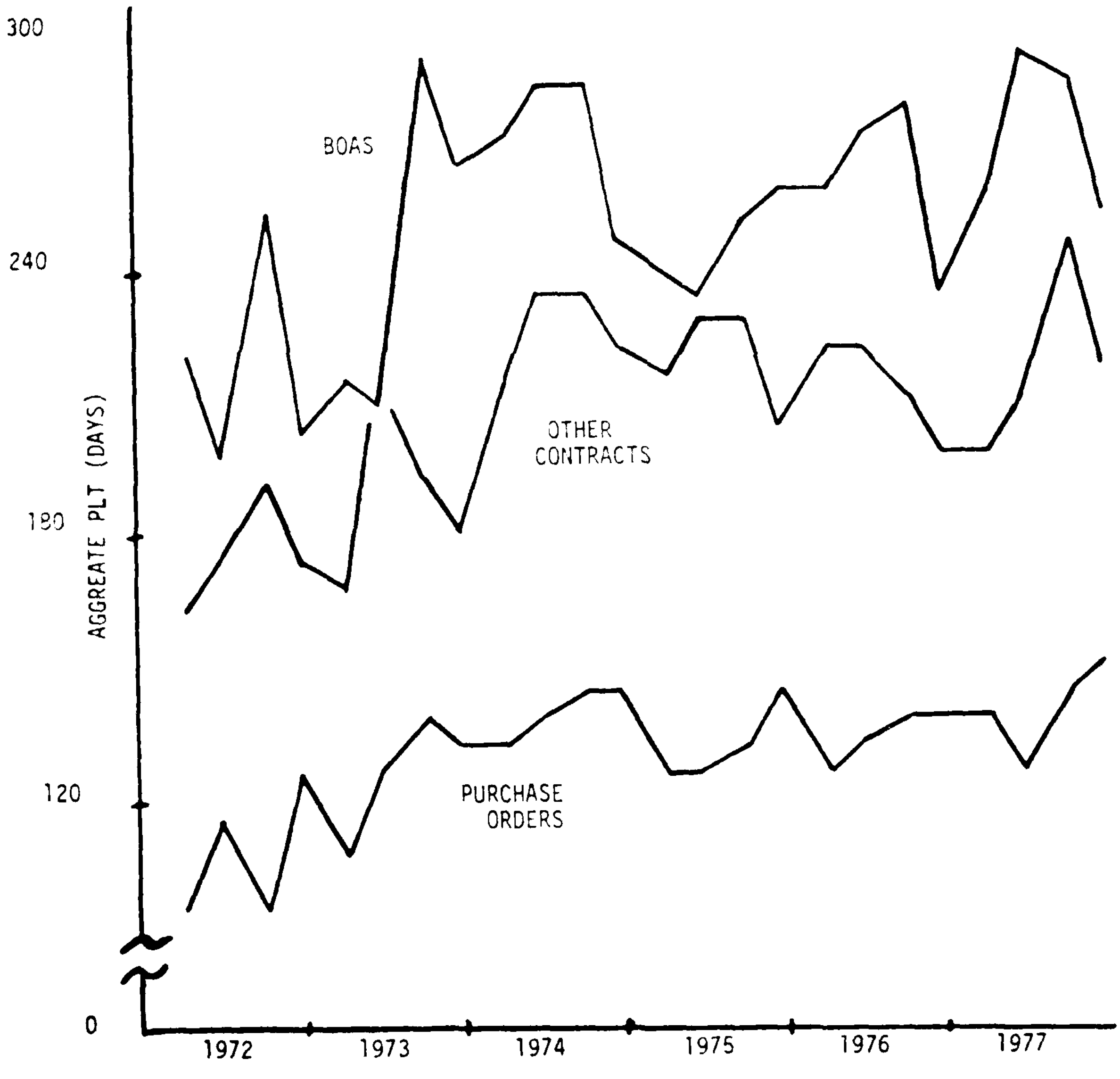
An item is usually bought using a single type of contract for a long period; then a new type may be used. For example, most aviation components are bought using a BOA. Finally the item may begin to be produced by several vendors, and TSARCOM will switch to a competitive buy. For an emergency order for a small quantity a purchase order may be used.

The following graph shows the quarterly average PLT for each of the three mainly used types. There is no question of the difference between purchase orders and the other two types; purchase orders are filled in much less time.

The line for BOA is noticeably above that for competitive contracts over $10000. This does not mean that using a BOA takes longer than the competitive process. Rather it is an indication of the type of items that are bought by the two different methods. TSARCOM uses the BOA for the type of aircraft-peculiar item that requires the experience of firms like Bell and Lycoming; these items will naturally take a long time to produce. When there is sufficient production experience there is an attempt to buy on open bid. By then due to learning-curve effects the PLT may be considerably reduced.

While a slight increasing trend is evident, it does not seem to be different for different contract types. Thus we have found a good method of separating items (at least aviation items) of different PLT lengths, but we have not been able to identify item types that show different trends. It would be foolhearty to believe that all items really follow a single trend, but we have no other evidence in our work with aggregate PLT.

CATALOG TRENDS



CHAPTER IV

FORECAST METHODS

4.1 Basic Model

Our problem was to find a method of using the available data, namely the item's own history as well as averages by contract type, to estimate the value that was most likely to be closest to the PLT which subsequently occurred.

Depending on which common criterion of "best forecast" we use, the best method would be the simple average or the median of all the item's history. The average works best when the criterion is root mean-square error (RMS) while the median minimizes the average absolute error (MAD). This is true only for a constant process with random variation.

If this simple model of the PLT process were complicated with a fixed trend (like inflation?) or seasonal cycles, they could be identified and removed before applying the average or median. However, observation suggests that this type of process may be described by randomly broken trends or something equally unpredictable. So we want a forecast method that can follow a trend for a while, but not get locked into it forever. We have had good experience predicting demand using moving averages, so we tried something similar here. A moving average includes only recent data, say the last two years, and thus does not put any weight on old trends.

There is a special problem with PLTs: The number of observations in a fixed time can vary. For items that are bought infrequently there may be only one, or even not any, buys in the past two years. This is where we can make use of averages over similar items on the assumption that they would reflect recent economic conditions.

We would also like to get a grip on a recent trend by considering buys that have not been shipped by the time the forecast is needed for the next buy. If we have a contract that is already a year old, and the average of previous contracts was only nine months, it seems like a good idea to average in the year to get a lead on the trend.

Finally, a note about evaluation: We felt that average absolute error

was a better criterion than RMS error because the latter tends to give too much weight to large errors. However, most forecasting studies use RMS error. We decided to rank the performance of our various forecast methods based on the above ideas by average absolute error and check this ranking against that of RMS error. As long as there was little difference we would use average absolute error.

The following sections show the formulas used for the forecast methods.

4.2 Notation

PLT_i = the i^{th} PLT in the previous 2 years

N = the last (most recent) PLT

F = the forecasted PLT

$DTSGNR_j$ = the signature date of the j^{th} PLT

M = the last buy placed on contract

Note: $i = 1...N$; $j = 1...M$; $M \geq N$

CAT_j = average of the most recent two quarters of the catalog average PLT for a certain* contract type; most recent period ending on the j^{th} buy's PWD date. Here $1 \leq j \leq M + 1$ where the $M + 1$ buy is the one we are trying to forecast.

NOW = the date of the PWD of the $M + 1$ buy.

$$\delta_j = 1 \text{ if } NOW - DTSGNR_j \geq \sum_{i=1}^{N} PLT_i/N\text{; 0 otherwise}$$

$$R = N + \sum_{j=1}^{M} \delta_j$$

4.3 Description of the Methods

PREV PLT (current method in CCSS):

$$F = PLT_N$$

2-YR AVG:

$$F = \frac{1}{N} \sum_{i=1}^{N} PLT_i$$

*Note: The contract type is assumed to be that of the M^{th} buy (the one preceding the current buy, which is not yet on contract) because this is the latest one that is on contract and thus has a known type.

EXTENDED AVG:

$$F = \frac{1}{R} \{ \sum_{i=1}^{N} PLT_i + \sum_{j=1}^{M} \delta_j \text{ (NOW-DTSGNR}_j) \}$$

COMBINATION M:

$$F = (\alpha)(F') + (1-\alpha)(CAT_{M+1})$$

where $\alpha = \frac{R}{R+C}$

F' is either the 2-YR AVG or the EXTENDED AVG forecast and C is a constant.

MEDIAN:

$$F = \frac{1}{2} \{PLT_A + PLT_B\}$$

where A = [R/2], B = [R/2 + 1]

and the brackets mean "greatest integer less than or equal".

INDEX:

$$F = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{CAT_{M+1}}{CAT_i}\right)(PLT_i)$$

CATALOG:

$$F = CAT_{M+1}$$

CHAPTER V

EVALUATION OF FORECAST METHODS

5.1 General Description of Methodology

The forecast methods presented in the previous chapter were evaluated bv feeding them real data and comparing the resulting forecast with the actual PLT that subsequently occurred. This was accomplished with a computer program and a data base both specially developed for this study. The way it was done may be considered a deterministic simulation. For each procurement the program looked at the buys in its past, computed a forecast based on the known PLTs of these buys (or any other information required by the forecast method to be evaluated), and compared this forecast to the PLT of the procurement under consideration. The amount of difference between the forecasted and actual PLTs, i.e. the observed error, was then treated as a statistical sample.

5.2 Data Base

The data base consisted of procurements for almost thirty thousand aviation components. Each procurement was characterized by the date the contract was signed, the type of contract, the date by which one-third of the total order was shipped, a code to identify the PLT as representative or not or based on a promised delivery date, and the total quantity and dollar value of the order. The unit price of the item was derived by dividing the last two values. It was assumed that the forecast was needed 90 days before the signature date of the contract. The PLT was computed by subtracting the contract date from the shipment date.

The figure shows the information used in forecasting a single item. This particular item had eleven buys. Characterized by shipment date, there is one in 1973, one in 1974, four in 1975, two in 1976, and three in 1977. The contract type is indicated by a letter at the left-hand end of each buy. There were six BOA calls in 1973 thru 1975, four competitive awards in 1976 and 1977, and one purchase order in 1977.

The left-hand end of each line is at the date that a forecast was made.


1972
1973
1974
1975
1976
1977

The tick in the middle is the contract signature date, and the right hand end is the shipment date. The PLT in days is marked above the segment representing the PLT.

The first buy, marked A_1, is not considered an observation because there is no previous data on which to base a forecast. This particular item has ten observations: A_2-A_6, C_1-C_4 and M_1. By contract type it has five BOA observations, three Competitive contract observations, and no Purchase Order observations. The following table gives the distribution of BOA observations; the distributions of the other two contract types were similar to the BOA distribution.

NUMBER OF OBSERVATIONS	PERCENT OF ITEMS GIVEN AT LEAST ONE OBSERVATION	
1	41.4	90.5%
2	21.9	
3	13.3	
4	8.4	
5	5.5	
6-10	8.3 (1.7 each)	
More than 10	1.1	

5.3 Editing

In general, an observation was required to have at least one buy shipped in the two-year period preceding the forecast date (the left hand end of the line). The data base contained all procurements beginning or ending in the six-year period 1972 thru 1977, except those whose PLT was more than 33 months or less than one day (obvious errors), which amounted to less than one percent of the total. About 65 percent of the buys were not used as observations because, for each, there were no procurements of the same contract type shipped in the two-year base period for that buy.

To eliminate a source of bias, only the observations shipped in 1976 and 1977 were used to evaluate forecasts. Only for those years could a full 33 month PLT observation be guaranteed a forecast to evaluate. For instance, if a 33 month PLT was shipped at the beginning of 1975, its

two-year base period would end at the beginning of 1972; thus it could not be used for evaluating forecasts (no data before 1972). But a 21 month PLT would have a good chance of having some buys in its base period, which would end at the beginning of 1973. Thus, if we utilized buys ending before 1976, we would tend to over-forecast thru no fault of the forecast method; rather it would be due to faulty methodology.

5.4 Definition of Aggregate Statistics

The forecast error was computed by subtracting the actual PLT from the forecast, and accumulated using the following formulas:

MAD = AV ABS ERROR = SUM (|ERROR|)/COUNT

BIAS = Average Error = SUM (ERROR)/COUNT

RMS = Root Mean Square Error = SUM ($ERROR^2$)/COUNT

where the SUM is taken over all observations by contract type, and COUNT is the number of observations in the SUM.

CHAPTER VI

RESULTS

6.1 Preliminary Results

This chapter presents the results of the study. First we present two sets of results from other sources. These results are shown to be similar to ours for the currently used forecast method (Previous PLT) and the TWO-YEAR AVERAGE method. The remaining sections of the chapter present our results for all the forecast methods and for demonstration points related to forecasting, all in the format defined in Section 6.2. Finally we show the cost saving expected if the best method is implemented.

The TARCOM study cited above also compared forecast methods. It was found that a simple two-year average outperformed the current policy (last representative buy).

(1977-1978) TARCOM RESULTS (MAY 1979)

(163 Items)

NUMBER OF OBSERVATIONS	396
MEAN PLT (MONTHS)	5.9
AVG ABS ERROR FOR PREV PLT	2.6
AVG ABS ERROR FOR 2-YR AVG	2.5

Adapted from (Procurement Lead Time Forecasting Analysis, Maryann Dominiak, TARCOM SA-79-14, May 1979). See report for additional work with other forecast methods and evaluation criteria.*

The following table shows the results of IRO work comparing the current forecast method with a simple two-year average. Again the average is favored slightly (has amaller average absolute error).

(1966-1973) TROSCOM RESULTS (NOV 1975)

	PROCUREMENT METHODS			
	COMPETITIVE	DIRECT PURCHASE	SOLE SOURCE	ALL
NUMBER OF OBSERVATIONS	5818	3127	265	9210
MEAN PLT (DAYS)(MONTHS)	4.7	4.4	4.5	4.6
AVG ABS ERROR FOR PREV PLT	2.5	2.2	1.8	2.4
AVG ABS ERROR FOR 2-YR AVG	2.4	2.1	1.6	2.3

*Recent work at ARRCOM also confirmed the conclusion that the PREV PLT method does not work well.

The next table gives results in the same format for IRO work with TSARCOM aviation components.

(1972-1977) AVSCOM RESULTS (JULY 1979)

	CONTRACT TYPE			
	BOA	COMPETITIVE	PURCHASE-ORD	ALL
NUMBER OF OBSERVATIONS	5120	1052	3784	10009*
MEAN PLT (MONTHS)	8.75	6.5	4.6	6.9
AVG ABS ERROR FOR PREV PLT	3.5	2.8	2.2	2.9
AVG ABS ERROR FOR 2-YR AVG	3.4	2.7	2.1	2.8

*Contains 53 buys on indefinite delivery contracts and delivery orders.

The above results with TARCOM, TSARCOM Troop Support and TSARCOM Aviation items all reflect the same conclusion: Average absolute error is smaller when recent PLTs are averaged than when only the most recently observed PLT is used as the forecast.

6.2 Final Results with Aviation Data

In the following sections we present the complete results of our work with the TSARCOM Aviation items. The presentation format is as follows:

- Objective
- Ranking by Average Absolute Error (MAD) and Root-Mean-Square Error (RMS)
- Spread of Forecast Error (where examined)
- Discussion

The results are presented by contract type, and for all types pooled. Under each is given the number of months average absolute error followed by its rank in parentheses, followed by the RMS and its rank. Notice the high degree of consistency across contract type and between MAD and RMS. No BIAS figures are shown because in every case it was very small.

RANKING OF FORECAST METHODS

Objective: To find the best PLT forecast method.

CONTRACT TYPE

Forecast Method	BOA		COMPETITIVE		PURCHASE ORD		All	
PREV PLT	3.5(8)	4.7(10)	2.8(8)	3.9(10)	2.2(9)	3.1(9)	2.9(8)	4.1(9)
2-YR AVG	3.4(6)	4.5(6)	2.7(6)	3.8(7)	2.1(6.5)	3.0(6.5)	2.8(6)	3.9(6)
UNSHIPPED INCL								
MEDIAN	3.4(5)	4.5(5)	2.7(4.5)	3.7(5)	2.1(6.5)	3.0(6.5)	2.8(5)	3.9(5)
AVERAGE	3.3(4)	4.5(4)	2.7(4.5)	3.7(5)	2.1(5)	2.9(5)	2.8(4)	3.9(4)
COMBINATIONS								
C=1	3.1(1)	4.0(1)	2.4(1)	2.4(1)	3.2(2.5)	1.8(2.5)	2.5(1)	3.5(2)
C=2	3.1(2)	4.0(2)	2.4(2)	3.2(1)	1.8(1)	2.5(1)	2.6(2)	3.4(1)
C=3	3.2(3)	4.1(3)	2.5(3)	3.3(3)	1.8(2.5)	2.5(2.5)	2.6(3)	3.5(3)
INDEX	3.4(7)	4.6(7)	2.7(7)	3.8(8)	2.1(8)	3.0(8)	2.8(7)	4.0(8)
CATALOG UP	3.5(9)	4.6(8)	3.0(10)	3.8(9)	3.0(10)	3.6(10)	3.3(10)	4.1(10)
CATALOG CONTR TYPE	3.7(10)	4.7(9)	2.9(9)	3.6(4)	2.0(4)	2.7(4)	3.0(9)	3.9(7)

SPREAD OF FORECAST ERROR (Months 95th Percentile)

	BOA	COMPETITIVE	PURCHASE ORD
PREV PLT	9	7	6
COMB M=1	8	6	5

Discussion: There is a 13% reduction of avg absolute error between the best method (COMB C=1) and the current method (PREV PLT). The improvement is consistent across contract type and for root-mean square and spread of errors. The poor performance of the CATALOG method based on the UP vs PLT relationship may be explained by the small difference in PLT between unit price classes (except the highest). See table in Section 3.4 at bottom of page 17.

FIRM DELIVERY DATES

Objective: To estimate improvement due to using firm delivery dates in forecast.

CURRENT METHOD

	BOA		COMPETITIVE		PURCHASE ORD		ALL	
WITHOUT FIRM	3.5(2)	4.7(2)	2.8(2)	3.9(2)	2.2(2)	3.1(2)	2.9(2)	4.1(2)
WITH FIRM	3.2(1)	4.4(1)	2.7(1)	3.8(1)	2.1(1)	3.0(1)	2.7(1)	3.8(1)

TWO-YEAR AVG

	BOA		COMPETITIVE		PURCHASE ORD		ALL	
WITH PRES. AGE	3.3(2)	4.5(2)	2.7(2)	3.7(2)	2.1(1)	2.9(1)	2.8(2)	3.9(2)
WITH FIRM	3.2(1)	4.3(1)	2.7(1)	3.7(1)	2.1(2)	3.0(2)	2.7(1)	3.8(1)

Discussion:

There were very few firm delivery dates in the data base. This experiment was accomplished by using the actual PLTs of the base-period buys even when they had not been shipped in time for the forecast. Thus the improvement must be considered an upper bound on that achievable by using firm delivery dates in this way.

Using the firm delivery date of the most recently placed contract instead of the actual PLT of the latest shipped buy achieved a 5.5% reduction in average absolute error. This was consistent over contract type and for RMS error.

Replacing present age with firm delivery date in 2-YR AVG improved forecasting a little, but not for purchase orders.

CONTRACT TYPE

Objective: To see if there is any advantage to ignoring contract type to increase the number of observations in the two-year average.

TWO-YEAR AVG INCLUDING UNSHIPPED

	BOA		COMPETITIVE		PURCHASE ORD		ALL	
SINGLE CONTR. TYPE	3.3(2)	4.5(2)	2.7(1)	3.7(1)	2.1(1.5)	2.9(2)	2.8(1)	3.9(2)
IGNORE CONTR. TYPE	3.1(1)	4.4(1)	2.8(2)	3.8(2)	2.1(1.5)	2.9(1)	2.8(2)	3.9(1)

Discussion:

The advantage of additional observations is cancelled by the lack of uniformity of the multi-contract data. The slight improvement was not consistent over contract type or between avg. absolute error and RMS error.

RECENT BUY EXPERIENCE AND PLT LENGTH

In order to see whether PLTs were shorter when there were recent buys average PLTs were computed for the two-year period 1976 thru 1977.

Following table compares average PLT for those buys with another buy in the previous two years vs those without. The averages are given by contract type, and for all contract types together (including a few buys on indefinite delivery contracts and a few delivery orders not included in the type breakout).

CONTRACT TYPE

	BOA	COMPETITIVE	PURCHASE ORD	ALL
NEW BUYS	9.4(5603)	9.3(519)	5.0(3154)	7.9(9262)
RE-BUYS	8.8(5120)	6.5(1052)	4.6(3784)	6.9(10009)

Overall it takes an average of one month less to produce items with recent experience.

PLT FORECAST VARIANCE

Objective: To estimate the variance of the forecast distribution.

Following table gives the coefficient of variation and mean PLT for three contract types and a pooled total. Data covers years 1976 thru 1977. Results are given for best forecast method and for current method for comparison. Based on RMS.

COEFFICIENT OF VARIATION BY CONTRACT TYPE

	BOA	COMPETITIVE	PURCHASE ORD	POOLED
COEFFICIENT OF VARIATION				
COMB C=1	.461	.495	.558	.499
PREV PLT	.535	.597	.683	.587
MEAN PLT (MONTHS)	8.8	6.5	4.6	6.9
NUMBER OBS.	5120	1052	3784	9956

Discussion:

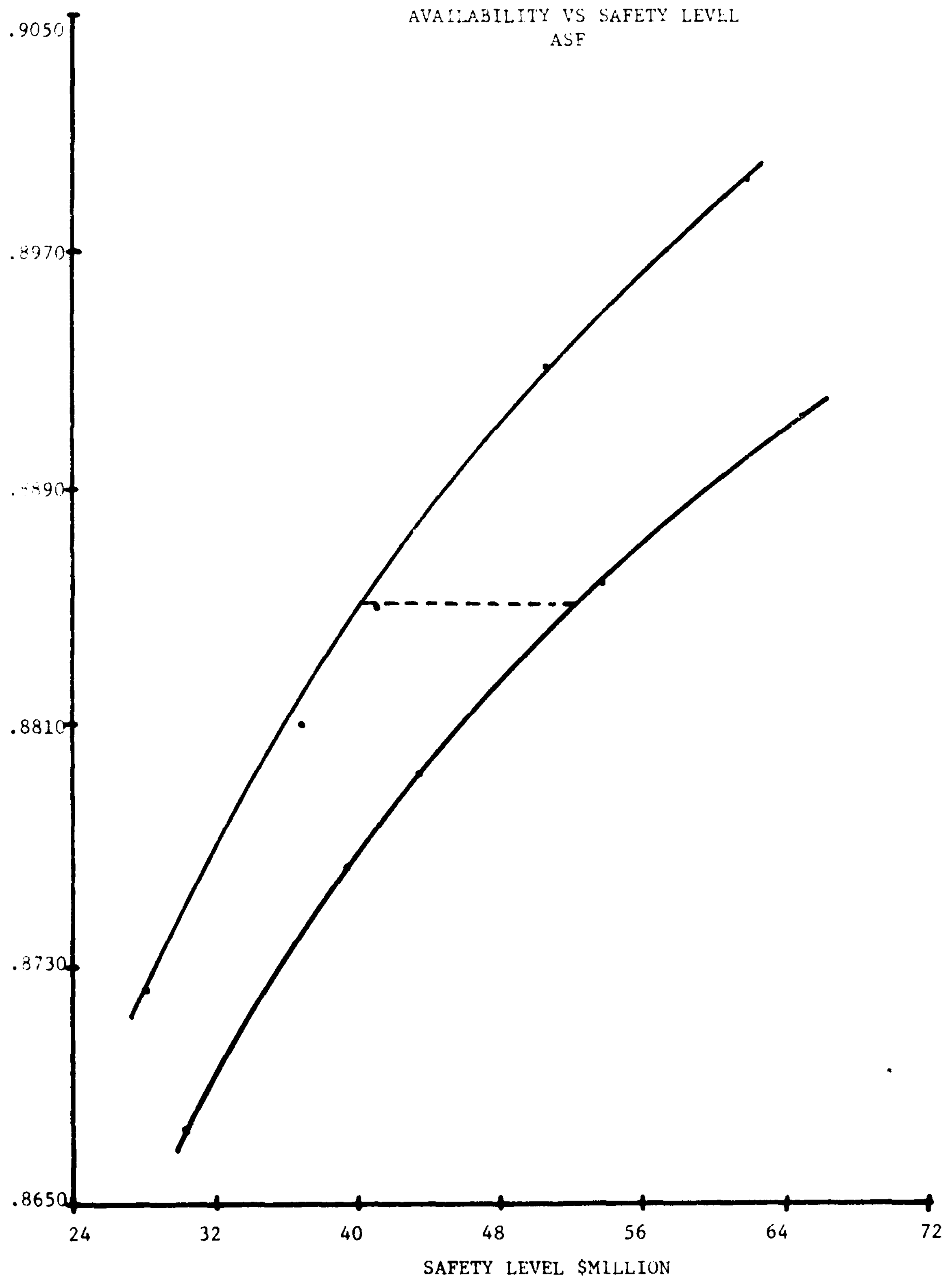
The forecast error variance for the best forecast method is about 15% less than that for the current method.

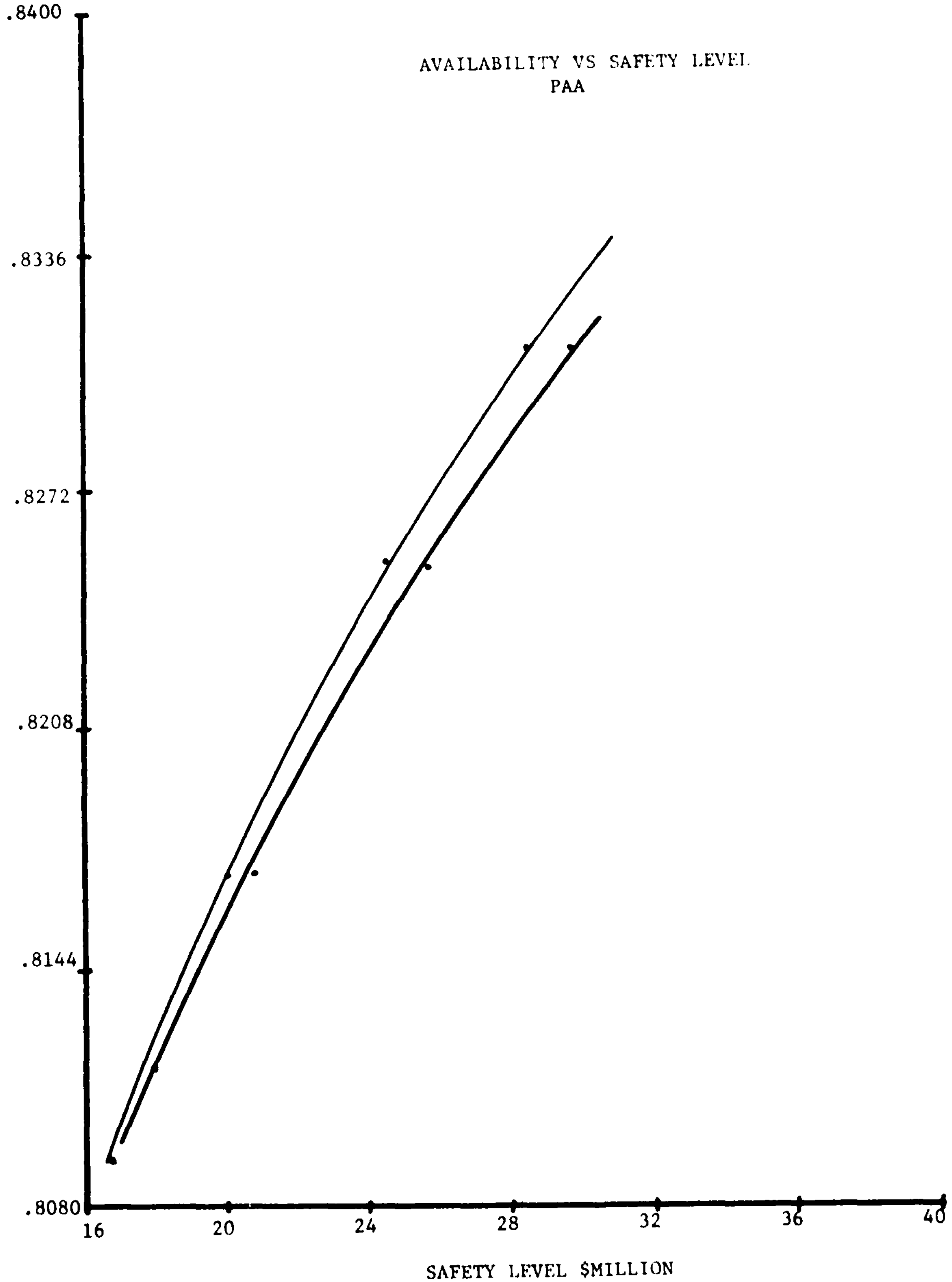
6.3 Cost Saving

The following charts can be used to estimate the cost savings achievable with the proposed forecast method. The first chart is for stock fund (ASF) and the second for procurement appropriation (PAA) of aviation components. Both charts assume that the safety level calculation includes the variance of the procurement lead time forecast.

For each component the budget strat data was used to compute the safety level and order quantity. From these the availability was projected. Each x-axis value is simply the sum of the dollar values of the safety levels of all the components; the y-axis value is the demand-rate weighted average of the availabilities. Four different values of backorder penalty cost were used to trace the curves. The upper curve is based on a coefficient of variation of PLT forecast equal to .5, the value for the Combination method with C=1; and the lower curve is based on .6, the value for the Current forecast method.

To estimate typical savings look at the ASF graph. At an availability of 0.885 on the vertical scale, the two curves are about $15 million apart as measured on the horizontal scale. This means we would expect a $15 million saving in safety level by using the Combination forecast method as opposed to the current method.


AVAILABILITY VS SAFETY LEVEL
ASF
.9050
.8970
.8890
.8810
.8730
.8650
24
32
40
48
56
64
72
SAFETY LEVEL $MILLION


AVAILABILITY VS SAFETY LEVEL
PAA
.8400
.8336
.8272
.8208
.8144
.8080
16
20
24
28
32
36
40
SAFETY LEVEL $MILLION

CHAPTER VII

CONCLUSIONS

From the work done by TARCOM and ARRCOM and our own work with AVSCOM data we conclude that the attempt to follow trends by basing the PLT forecast on only a single, last representative buy has failed. An average of the last two years of representative buys performs better as a forecast method. This confirms the high degree of variability of PLT values observed by TARCOM, ARRCOM and IRO studies. There is usable information in the procurement history of the item, and an average of the recent buy experience is a better way to access this information than just the most recent buy.

We have also found that the information inherent in the fact that a recent order has reached an age greater than the average of previous orders, can be harnessed to improve the forecast. Presumably, these unshipped orders give us the handle on trend that we were trying to get by using only the last representative buy. By this approach we are using even more recent data, buys that are not yet "representative."

Another finding is that a two-quarter average of all buys for the same contract type that is to be used for the buy whose PLT we are attempting to forecast, can be used to add valuable information when the item's own history is insufficient. The fact that using this catalog average by itself as a PLT forecast method gave poor results, but using it to fill in for items with few recent buys gave the largest improvement of any of the techniques tried, suggests that its value is mainly as a supplement. This is also confirmed by the poor performance of the INDEX method.

Since the catalog average did perform better than the currently used method, it may also have some value as a forecast method by itself when there is no recent history, i.e., no shipments in the last two years. In this application it may tend to underforecast slightly because we found a slight difference in the average PLTs for items with no recent buys and those with recent buys. Items with no shipments in the preceding two years had PLTs about one month longer.

An experiment suggested that including PLTs calculated from the firm delivery dates of unshipped contracts in the two-year average instead of the

present age improved performance a little. However, more work needs to be done on this using more suitable data. If results are positive, perhaps current vendor estimates could also be used in forecasting PLT.

Attempting to group the catalog by a unit price stratification instead of contract type deteriorated forecast performance. This was surprising because the stratification seemed to separate different values of PLT efficiently. This work could be extended by applying an inflation adjustment to the unit prices.

Even though our best forecast method represents a significant improvement there still remains an average absolute error of two and one-half months. We have no way of knowing whether this error represents an irreducible random variation or a predicatable change given other information. Further empirical work with Box-Jenkins auto and cross-correlation should reveal something along these lines. A contact at the University of Wisconsin has expressed interest in this work. Experimenting with Markov or Kalman models may also provide insight.

One of the goals of this study was to determine whether a significant increase in requirements may cause an increase in PLT. Work was begun with a stratification (suggested by CERCOM) on dollar value of the order, but an unfortunate accident with the data base terminated the work before any results were obtained.

Other problems that could be studied include the question of independence:

Is variability independent of stock position, or will we see expedited shipments when assets are low?

Theoretical questions on variance estimation can be studied empirically:

Can we assume that orders cross (an earlier order delivered later)?

What approach do we use to measure variance when the PLT proocess is nonstationary?

Should we be accounting for the variance of PLT, and especially ALT, at all? The effect of implementing our PLT variance as a coefficient of variation will have the effect of assuming the same amount of variation for the ALT as the PLT. Should they be different?

APPENDIX I

LACK OF AGREEMENT BETWEEN CCSS FILES

In developing the data base, some problems arose in verifying the accuracy of the data. The PLT averages showed a lack of consistency between different files. The following notes give our findings based on a manual check of fifty important items. The files are: National Stock Number Master Data Record (NSNMDR) and MILSCAP Master File (MMF).

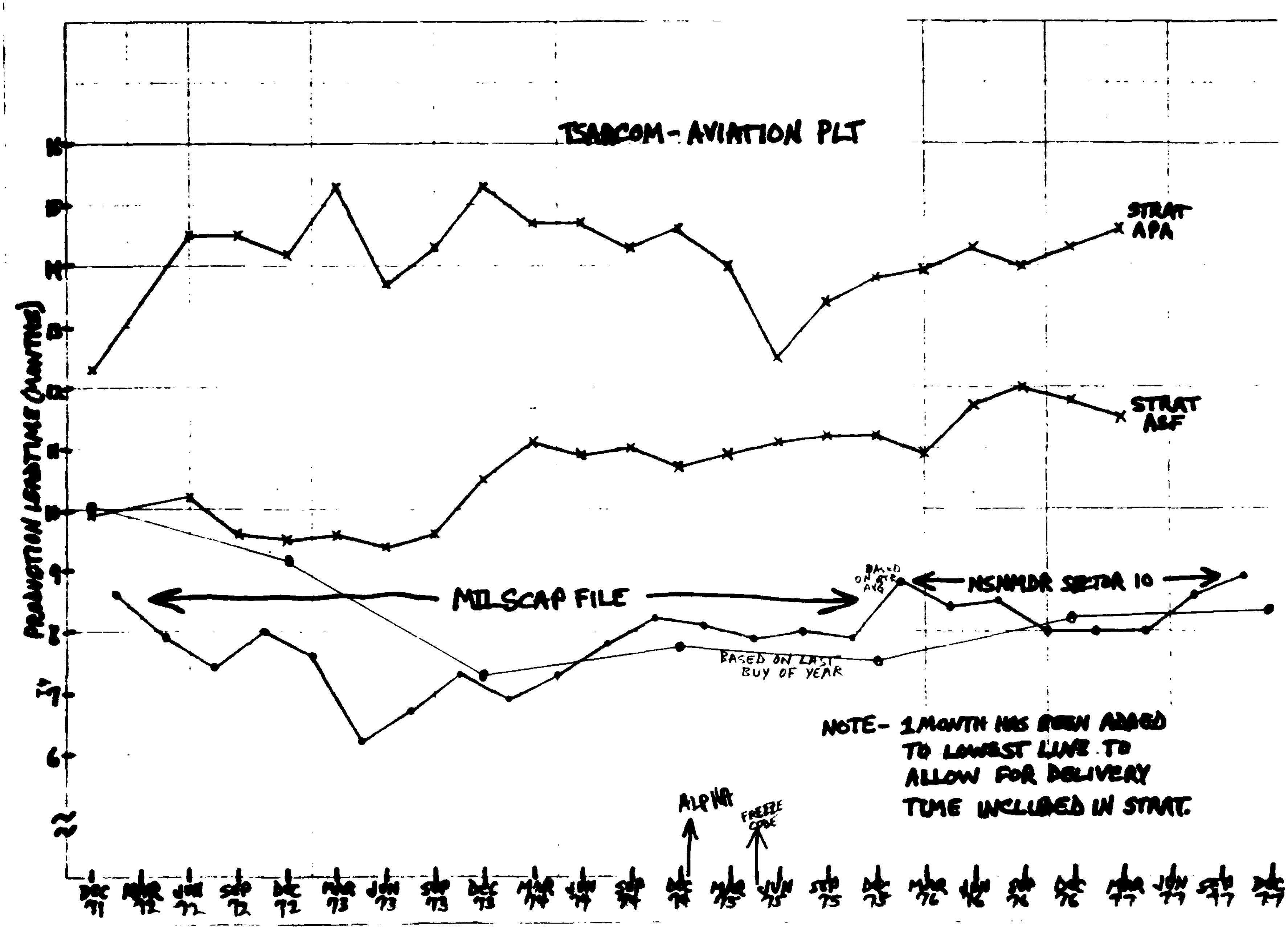
NSNMDR Sector 10 seems to agree with MMF.

PROLT in Header (NSNMDR) seems too big compared to Sector 10; however, results with a small group of items show reverse effect.

Sector 13 seems to agree with Header (except for rounding).

Freeze code usage was unexplained in two follow-up calls. This may be cause of disagreement between Header and Sector 10.

The following graph compares our data base (MMF and Sector 10) with the Budget Strat (Sector 13). The two lines show the dollar weighted average PLTs from Sector 13 for procurement appropriation and stock fund items respectively. The lower lines are an average weighted by number of buys and a PLT based on the last buy of the year, both from our data base (MMF and sector 10). It was thought that the line based on the last buy of the year would match the sector 13 data because the latter is presumably based on the latest representative buy. It can be seen that this line follows the stock fund line closely until the end of 1972. At that point the two lines diverge. Freeze codes were implemented in 1975, and could thus explain some of the difference from that year on. We have no explanation for the divergence in the year 1973 and the three-month difference in 1974. Dollar weighting of the sector 13 results could be emphasizing longer PLTs, but we know by checking individual items that differences occur that can not be explained by relative weighting of different items.



TSARCOM - AVIATION PLT
PRODUCTION LEADTIME (MONTHS)
16
15
14
13
12
11
10
9
8
7
6
STRAT APA
STRAT ALF
MILSCAP FILE
NSNMDR SECTOR 10
BASED ON QTR AVG
BASED ON LAST BUY OF YEAR
ALPHA
FREEZE CODE
NOTE - 1 MONTH HAS BEEN ADDED TO LOWEST LINE TO ALLOW FOR DELIVERY TIME INCLUDED IN STRAT.
DEC 71
MAR 72
JUN 72
SEP 72
DEC 72
MAR 73
JUN 73
SEP 73
DEC 73
MAR 74
JUN 74
SEP 74
DEC 74
MAR 75
JUN 75
SEP 75
DEC 75
MAR 76
JUN 76
SEP 76
DEC 76
MAR 77
JUN 77
SEP 77
DEC 77

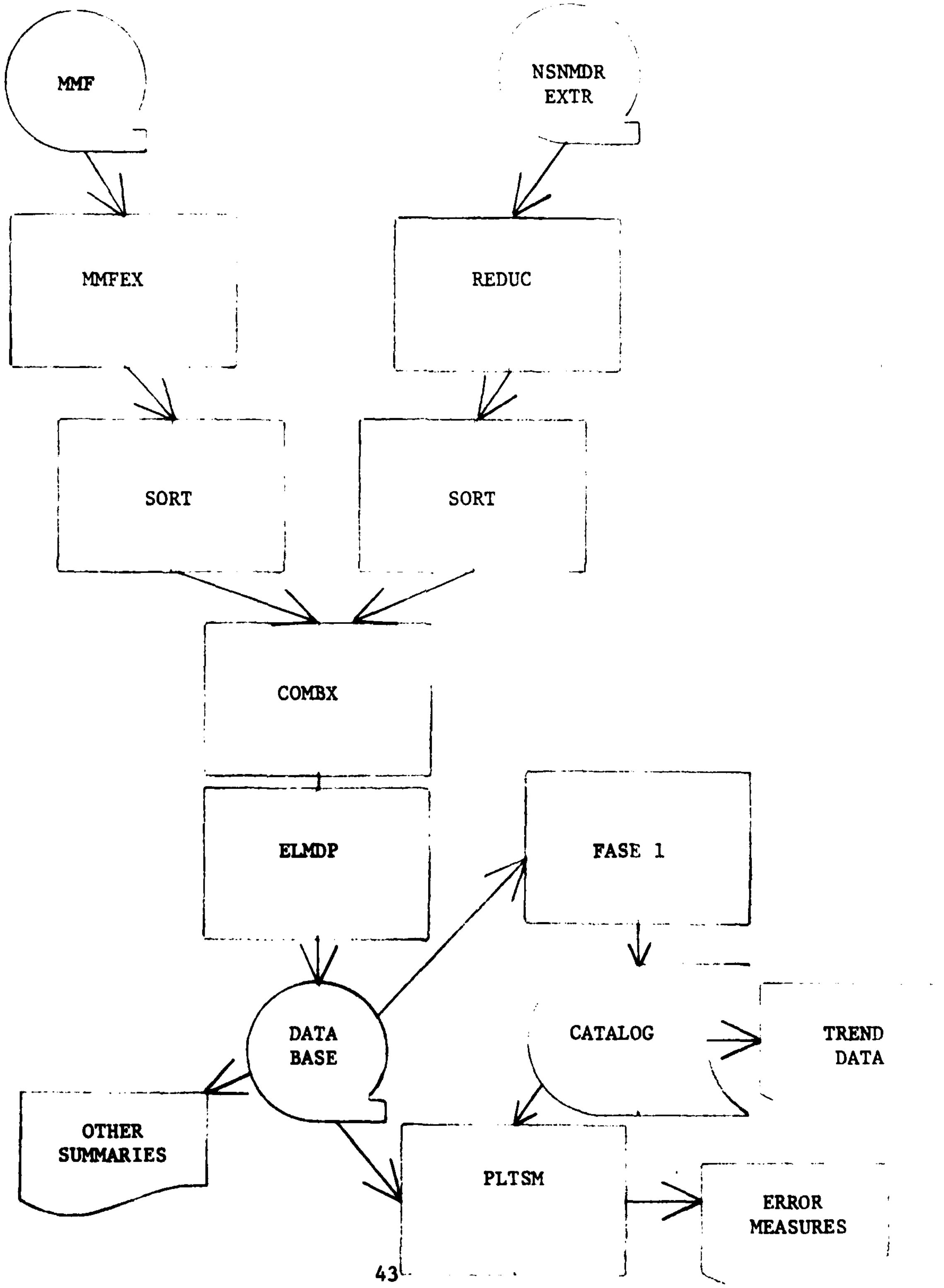
APPENDIX II

DATA PROCESSING + EDITING

The following chart elaborates the data processing that was performed in developing and analyzing the data base. Following the chart are descriptions of the programs referenced on the chart. Finally there is a table showing the number of procurements edited from the data base, and the order in which which it was done.

SYSTEM CHART

DATA PROCESSING



DESCRIPTION OF PROGRAMS

MMFEX collects contract data, CLIN data and shipment data for each contract. If 1/3 of total of all CLINs for any NSN ordered on the contract has been shipped, a record is output to the data base.

Each record contains NSN, DT-CONTRACT, Date by which 1/3 shipped, Total amount shipped (qty and $), Contract PIIN, etc.

REDUC selects Sector 10 from extract.

COMBX reformats Sector 10 data to look like data base record. Keeps only representative buys.

ELMDP eliminates duplicate records (due to overlap of MMF and Sector 10 coverage).

FASE1 averages PLTs by contract type and quarter.

PLTSM simulates forecast methods and collects and displays error statistics for evaluation.

<u>EDITING SUMMARY</u>

74824	Buys in original data base.
205	Removed because item had no NSN.
573	Removed because PLT was less than one day or more than 1000 days.
1299	Removed because shipped before 1972.
45029	Removed because there were no shipments in two-year period ending 90 days before contract was signed.
17709	Removed because the shipment was not in 1976 or 1977.
46	Removed because they were indefinite delivery contracts.
7	Removed because they were delivery orders on contracts of other Government agencies.
9956	Observations remain.

Contract Type Breakout:

5120	BOA
3784	Purchase Orders
1052	Competitive Contracts

BIBLIOGRAPHY

[1] Davis, Allan S., "An Investigation of Selected Business Indicators as Related to Aerospace Materials Leadtime," May 1975, Air University, LD33688A.

Investigates utility of selected published economic indicators in predicting movement of aerospaces materials lead times. Computed composite index for lead time of ten randomly-selected materials used in aircraft components. Used six values from April 1972 to February 1975. Compared to six series from Business Conditions Digest. Found that three series' (vendor performance, executive judgement of level of inventories, and capacity for prospective operations) seemd to provide an "alert of one to four months of impending significant lead time changes."

[2] Engleman, J. L., "Analysis of Proposed Stock Range Rules," April 1975, US Navy Fleet Materiel Support Office, LD33385A.

Attempted to group items for purpose of predicting unit price of a new item according to the group in which it falls. Tried various combinations of following identifiers to form groups: item nomenclature up to first comma, space or hyphen; Federal Stockage Class; Navy Cognizance Code. Most "groups" had only one item. Groups with several items show high dispersion of unit prices. Use of inflation factor did not help. Using entire nomenclature did not help. No method of grouping gave acceptable results.

[3] Hill, Joseph S., "Analysis of Production Lead Time for Missile Repair Parts with Cable Assemblies and Wiring Harnesses," April 1975, USAMC Intern Training Center, LD33435A.

Results suggest that PLT is influenced by total contract cost, but data was insufficient.

[4] ALRAND Working Memo 231 (ASO), "Family Replacement Factors for Aviation Materiel," 3 September 1974.

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